Faculty of Engineering

StormPav Green Pavement System as Permeable Road for Detention and Conveyance of Stormwater

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

This study focuses on a value-added function to StormPav Green Pavement System, that is not only designed to store stormwater but to act as a conduit to drain stormwater in a typical commercial environment. This system is a form of permeable road, in which multi-unit small chambers are used to overcome the problem of big stormwater storage structure; and at the same time could provide a greater strength in its interlocking manner for vehicles transportation. This structure is analysed of its capability to store and convey stormwater from roof and road catchments that is subjected to 10-year ARI design rainfall with durations ranging from 5 to 180 minutes. The added function could only be executed when appropriate inlet and outlet design are decided. Computer models are incorporated in this study. Comparison of Storm Water Management Model (SWMM) and SolidWorks Flow Simulation (SWFS) models is performed. Results show that both models are reiterating each other, suggesting that the confidence level of the model verification is enhanced. Visualization of flow within the system is also demonstrated. Results indicate that inlet and outlet design sizes of 100 mm and 190 mm x 700 mm respectively could provide optimum filling, ponding and draining effects. The system is able to reasonably alleviate the peak discharges at the outfall. Besides that, by comparing with conventional drainage system, the discharge reduction after implementing the StormPav system reports the highest reduction in discharge (approximately 80% reduction) occurred for the 5-minute design rainfall duration, while the lowest reduction in discharge (approximately no reduction) occurred for 180-minute design rainfall duration. This means that the structure has reached its limit or range of service. In conclusion, findings show that the StormPav system has demonstrated the capability of conveying and storing stormwater up to 180-minute, 10-year ARI design rainfall.

Keywords: Permeable road, on-site detention, urban drainage, StormPav, SWMM.

Sistem StormPav Green Pavement sebagai Sistem Menakung dan Mengalirkan Air Hujan

ABSTRAK

Kajian ini memfokuskan fungsi nilai tambah kepada sistem StormPav Green Pavement yang bukan sahaja direka untuk menakung air hujan tetapi juga berfungsi sebagai saluran yang mengalirkan air hujan dalam premis komersial. Sistem StormPav dapat diklasifikasikan sebagai jalan telap, di mana pelbagai unit ruang kecil yang diinovasikan untuk mengatasi masalah struktur simpanan air hujan yang besar, dan pada masa yang sama sistem ini dapat menambahkan kekuatan dalam ciri cantuman untuk mengatasi tekanan semasa pengangkutan kenderaan. Struktur ini dianalisa dari segi keupayaan untuk menakung dan mengalirkan air hujan dari kawasan bumbung dan kawasan jalan berdasarkan 10 ulang tahun kejadian (ARI) dalam jangka masa 5 hingga 180 minit. Fungsi tambahan dalam kajian ini hanya dapat dilaksanakan apabila reka bentuk saiz yang sesuai untuk inlet dan outlet diperolehi. Kajian ini melibatkan model komputer. Perbandingan antara model SWMM dan model SW Flow Simulation telah dijalankan. Keputusan menunjukkan bahawa kedua-dua model serasi antara satu sama lain, dan oleh itu, meningkatkan tahap keyakinan pengesahan model. Visualisasi aliran dalam sistem StormPav juga ditunjukkan. Keputusan menunjukkan bahawa saiz 100 mm inlet dan saiz 190 mm x 700 mm outlet dapat memberikan kesan optimum pengisian, penakungan dan pengaliran. Berdasarkan keperluan MSMA, sistem StormPav mampu mengurangkan puncak aliran air di hilir. Sejajar dengan itu, perbandingan antara sistem perparitan konvensional dengan selepas perlaksanaan sistem StormPav menunjukkan pengurangan aliran air dan peratusan pengurangan aliran yang tertinggi ialah ketika reka bentuk hujan untuk tempoh 5 minit, anggaran 80%, manakala tempoh 180 minit memberi pengurangan peratusan yang paling rendah, iaitu hampir tidak ada pengurangan. Hal ini bermakna struktur telah mencapai had perkhidmatan.

Kesimpulannya, kajian menunjukkan bahawa sistem StormPav telah menunjukkan keupayaan penyimpanan dan pengairan air hujan sehingga 180 minit untuk 10 ARI.

Kata kunci: *Jalan telap, detensi di-tapak , saliran air bandar, StormPav, SWMM*

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ARI	Average Recurrent Interval
ASCE	American Society of Civil Engineers
BMP	Best Management Practice
CFD	Computational Fluid Dynamics
DID	Department of Irrigation and Drainage
HDPE	High-density Polyethylene
IBS	Industrialized Building System
LID	Low Impact Development
MSMA	Manual Saliran Mesra Alam
NCSPA	National Corrugated Steel Pipe Association
OSD	On-site Stormwater Detention
PUB	Singapore Public Utility Board
RANS	Reynold-averaged Navier-Stokes
SWMM	Storm Water Management Model
SWFS	SolidWorks Flow Simulation
TxDOT	Texas Department of Transportation
USDC	Underground Stormwater Detention Chamber
US EPA	United State Environmental Protection Agency

CHAPTER 1

INTRODUCTION

1.1 Background

Models of permeable roads are available since 1960s in the hopes of reducing floods, raising water tables and replenishing aquifers. To date, permeable roads are generally designating a subsurface storage to capture portion of stormwater runoffs (Ronalds & Zhang, 2017; Ronalds et al., 2017). A typical permeable road system consists of a surface pavement layer, a thin bedding layer of fine aggregate, an underlying coarse aggregate layer as base course and sometimes, a filter layer or fabric installed at the bottom (Chowdhury et al., 2016). These models are further described in the Chapter 2. Generally, its principle is illustrated in Figure 1.1, in which the detention of water comes first, then followed by a delay discharge through a control at outlet.

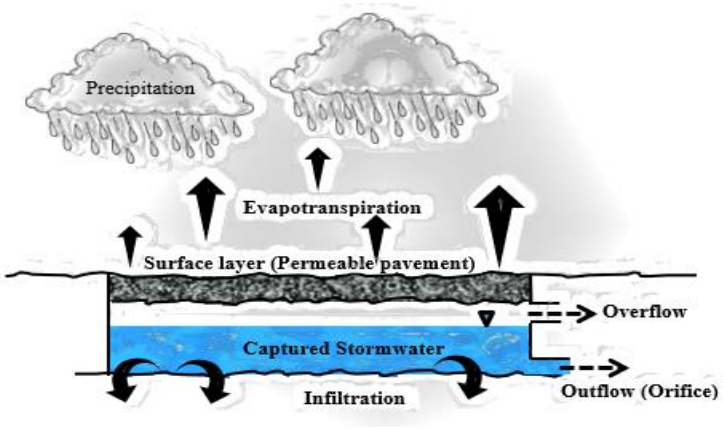

Figure 1.1: Schematics of Conventional Permeable Road

The water balance of the system depicted in Figure 1.1 could be derived as volume of water entering the system equals to volume of water being captured plus losses through infiltration, evapotranspiration, orifice and overflow (Subramanya, 2008; Mah et al., 2018c).

Basically, it follows the water budget equation or hydrologic equation where mass inflow subtracts mass outflow is the change in mass storage.

In normal practice, drainage engineers tend to pay more attention to the storage capacity for safety purposes. They tend to design the volume of storage space equals to potential amount of stormwater runoff plus additional minimum spaces reserved for adverse climates (DID, 2012). As a result, the storage structure could end up as a big structure depending on the size of the contributing upstream catchments.

1.2 Problem Statement

Along with the growing urbanization at a rapid rate, development of permeable road needs to be able to cater for and hold the increasing amount of runoff volume, thus, it is expected that a big storage structure is required. Big storage structure incurs higher cost in terms of construction and the associated safety precaution devices that should come along with the structure. Yet, it is possible to reduce the storage structure without compromising the reduction of stormwater impacts a storage structure could provide. In the case of a permeable road, the subsurface storage could be modified to have a function of stormwater conveyance. The voids within the storage structure provides the ponding effect that attenuates a hydrograph peak (Mah et al., 2014; Mah, 2016). At the same time, manipulating the outlet could allow the captured stormwater to flow (Urbonas & Stahre, 1993; Heiner & MacKenzie, 2015). Meaning, detention of stormwater provided by a storage volume can be released by the outlet structure. This filling and draining effect could reduce the size of the storage structure. Hence, the permeable road not only captures stormwater, but also a conduit to transfer water from one point to another point.

The specific type of permeable road model that this project is investigating, is named StormPav Green Pavement. The details of the product are described in the Chapter 2. This study is investigating an added function of StormPav Green Pavement to transport stormwater runoff on top of it as a stormwater detention structure. To accommodate the investigation of flow mechanism of such permeable road, computer modelling of drainage system is usually applied before an actual road is built. Computer modelling also provides necessary information to assist the construction of the road.

1.3 Objectives

The aim of this study is to focus on the workability of StormPav Green Pavement that flows stormwater underneath its pavement. Benchmarking to the requirement of Urban Storm Water Management Manual for Malaysia (Manual Saliran Mesra Alam or MSMA), post-development peak hydrographs of a development scheme should be lowered with stormwater control measures so that the concept of "saliran mesra alam" could be achieved. StormPav fits in as a new stormwater control measure. By manipulating the inlet and outlet of the system in computer simulation, StormPav Green Pavement will show the capability to store and convey stormwater from premises. As such, the objectives of this study are:

i. To set up a numerical model that represent StormPav Green Pavement and its flow mechanism;

ii. To investigate the effect of stormwater inlet and outlet size on the performance of the above mentioned permeable road system to allow ponding, filling and draining effects; and

iii. To analyse the ponding, filling and draining effects with regards to MSMA requirement.

1.4 Scopes of Work and Structure of Thesis

This study presents on the capability of a permeable road to convey stormwater underneath its pavement in a typical commercial area. This research brings MSMA to another level by combining features so that multipurpose structure is introduced and promoted. In a way, it is also a realization to wise use of expensive land assets. A permeable road that receives and flows stormwater is designed. Computer modelling is done to achieve the objectives of this study. The thesis is organized into five chapters as follows;

Chapter 1: This Chapter includes the introduction of the study which discusses the general view of the topic, problem statement, objectives as well as the scope of the study;

Chapter 2: This Chapter includes the literature review, in which necessary information are presented in detail. This involves stormwater management, conventional and latest development of permeable roads, StormPav Green Pavement, design criteria, as well as the modelling of stormwater systems;

Chapter 3: This chapter includes the methodologies used in the current study;

Chapter 4: This chapter includes the findings obtained from computer modelling. Tables, graphs, as well as appropriate figures are presented and analyzed to investigate the objectives of the study;

Chapter 5: This chapter includes the conclusions and research outlook for the future.